Europäisches Patentamt
European Patent Office
Office européen des brevets

(19)

(11) Publication number: **0 294 826 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 88109267.0

(51) Int. Cl.⁴: **G10K 11/34**

(22) Date of filing: **10.06.88**

(30) Priority: **12.06.87 JP 147292/87**

(43) Date of publication of application: **14.12.88 Bulletin 88/50**

(84) Designated Contracting States: **DE FR GB NL SE**

(71) Applicant: **FUJITSU LIMITED**
1015, Kamikodanaka Nakahara-ku
Kawasaki-shi Kanagawa 211(JP)

(72) Inventor: **Kawabe, Kenji Fujitsu Limited**
Patent Department 1015 Kamikodanaka
Nakahara-ku Kawasaki-shi Kanagawa 211(JP)
Inventor: **Watanabe, Kazuhiro Fujitsu Limited**
Patent Department 1015 Kamikodanaka
Nakahara-ku Kawasaki-shi Kanagawa 211(JP)
Inventor: **Namiki, Fumihiro Fujitsu Limited**
Patent Department 1015 Kamikodanaka
Nakahara-ku Kawasaki-shi Kanagawa 211(JP)
Inventor: **Iida, Atsuo Fujitsu Limited**
Patent Department 1015 Kamikodanaka
Nakahara-ku Kawasaki-shi Kanagawa 211(JP)
Inventor: **Shimura, Takaki Fujitsu Limited**
Patent Department 1015 Kamikodanaka
Nakahara-ku Kawasaki-shi Kanagawa 211(JP)

(74) Representative: **Sunderland, James Harry et al**
HASELTINE LAKE & CO Hazlitt House 28
Southampton Buildings Chancery Lane
London WC2A 1AT(GB)

(54) Ultrasonic transducer structure.

(57) In an ultrasonic transducer having a matrix of piezoelectric elements an L-shaped printed wiring board (6′, 3′) is bonded to an array (1b) of piezoelectric elements (1). The bonding points of the L-shaped printed wiring board to respective piezoelectric elements (1) are located at edge portions of respective back electrodes (2A) of the elements. The other branch of the L-shaped printed wiring board (6′, 3′) is extended vertically to the surface of the piezoelectric element matrix. A backing plate (15) is formed by molding on the back side of the piezoelectric element matrix leaving the top of the L-shaped printed wiring board protruding from the molded surface of the molded backing plate (15).

To produce this structure a flexible printed wiring board (6, 3) is provided with a wiring pattern having bonding areas (34) positioned corresponding to a matrix of piezoelectric elements (1). After bonding, the printed wiring board (6, 3) is cut and bent vertically to the matrix surface to form the L-shape. The matrix of piezoelectric elements (1) may be cut out from a large-size piezoelectric element (1′) before the molding of the backing plate (15) or after its molding.

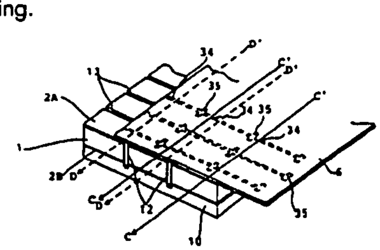


FIG. 3 (b)

EP 0 294 826 A1

Ultrasonic transducer structure.

The present invention relates to a structure of ultrasonic transducer, for example for use in ultrasonic diagnosis or fault detection.

Ultrasonic tomography is widely used in diagnosis or in failure or fault detection in various materials. In such applications, a transducer head that radiates ultrasonic pulse waves and receives their echoes from various parts of a target is provided with a plurality of piezoelectric elements arranged in an array with a predetermined pitch. Such transducer head arrays are called linear arrays, phased arrays or convex arrays, etc., according to the arrangement of piezoelectric elements and the method by which the output waves are scanned.

Electronic pulses for energizing the piezoelectric elements are controlled so as to shift in phase one with respect to another so as to provide ultrasonic wave radiation in a beam directed in a specific direction or to provide beam focus at a desired point. By controlling the phases of electronic pulses applied to respective piezoelectric elements, the direction of an output ultrasonic wave beam or its focus can be varied. However, such control can be effected only in a plane coplanar with the array. This plane is called the azimuthal plane. Beam scanning is effected in azimuthal directions. Beam scanning cannot be effected in directions orthogonal to the azimuthal plane. These directions are called elevation directions in the art. In the elevation directions, a beam has a fixed expanse determined by the length of each piezoelectric element and the wavelength of the output ultrasonic wave.

In order to obtain higher resolution in azimuthal directions, that is, higher azimuthal resolution of an ultrasonic tomogram, it is necessary to reduce the pitch of the piezoelectric elements in an array, and to reduce the size of the elements. In a transducer head for ultrasonic tomography, 128 piezoelectric elements each 0.55 mm wide and 15 mm long are arranged with a pitch of 0.6 mm, for example. However, in order to attain higher resolution or to vary focal length in elevation directions, it is necessary in effect to divide up the piezoelectric elements along their lengths (in the directions of elevation) and so to provide arrays arranged in parallel to each other, so that the piezoelectric elements are arranged in a matrix. However, there then occurs a difficulty in providing wiring to each of the piezoelectric elements. So, in the state-of-the-art devices only three arrays or columns of piezoelectric elements are arranged in the elevation direction. Finer pitch and the more array columns in the elevation direction are desirable.

In order to make more apparent the difficulty of wiring in an ultrasonic transducer head, and to make merits of embodiments of the present invention more apparent, the problem of wiring to each of the piezoelectric elements of a head will be explained and described.

Fig. 1 shows an example of a transducer head used for ultrasonic diagnosis. In the following explanation, a transducer head for ultrasonic tomography which is used for diagnosis will be referred to as an example, but the explanation can be extended to other applications such as an ultrasonic failure detector, or ultrasonic reflectometer, etc.

The transducer head 20 shown in Fig. 1 radiates ultrasonic pulse waves from an acoustic window 21, through which the ultrasonic waves pass freely. The transducer head 20 is contacted with its window 21 to a specimen which is to be tested or to be diagnosed. Ultrasonic waves are radiated through the acoustic window 21 to the specimen, a human body for example (not shown). Reflected waves from various parts of the specimen, such as human organs for example, are detected by the same head 20, converted into electric signals, and transferred to a processor (not shown) by a multicored cable 22. In the processor, the detected signals are treated in a manner somewhat like that used in radar technology and provide a tomographic image of objects in the human body.

A piezoelectric transducer unit has a structure as shown in Fig. 2(a). A piezoelectric element 1 is sandwiched by electrodes 2A and 2B. By applying electric potential between these electrodes, the piezoelectric element 1 is energized and shrinks or stretches to generate an ultrasonic wave. On the other hand, if an echo of an ultrasonic wave reaches the element, an electric potential appears between the electrodes 2A and 2B. In a transducer head, a plurality of such piezoelectric transducer units are arranged in an array, and a number of such arrays are further aligned in parallel to each other to form a matrix as shown in Fig. 2(b). In the Figure, three arrays of piezoelectric elements are arranged in a matrix of three columns.

As shown in Fig. 2(b), on the lower surface of a piezoelectric element 1 a front matching layer 10 is provided for matching the acoustic impedance of the piezoelectric element 1 to that of the material which includes the target of diagnosis or detection in order to transmit sound energy effectively into the material, a human body for example. The words "front" and "back" will be used hereinafter to designate a direction or position in a direction in which an ultrasonic wave is radiated from a piezoelectric element and an opposite direction respec-

tively. The front matching layer 10 usually has a thickness approximately equal to 1/4 wavelength of the ultrasonic waves propagating in the matching layer 10. The front electrodes 2B of the elements are electrically connected to each other and grounded. This connection is usually effected by using a conductive material for the front matching layer 10. In front of the front matching layer 10 an acoustic lens (not shown) is provided for focussing the ultrasonic waves in the direction of elevation. This acoustic lens is sealed to the case 23 of the transducer head 20, and provides the acoustic window 21.

The matrix of the piezoelectric elements is formed by cutting a large-size piezoelectric element in both azimuth and elevation directions to produce first slits 12 and second slits 13 which are orthogonal to each other. The back electrodes 2A must be connected to respective lead wires. As shown in Fig. 2(b), piezoelectric elements in arrays at opposite side edges of the matrix can be connected directly to printed wiring boards 11, which have a plurality of contact areas arranged in positions to meet respective piezoelectric elements, and wirings to those elements are provided on the printed wiring boards 11. However, it is impossible to attach a printed board directly to the array in the middle column of the matrix. The reason is as follows. On the back side (upper side in the Figure) of the piezoelectric elements a backing plate 15 is provided as shown in Fig. 2(c). The backing plate 15 is made of material which absorbs ultrasonic waves, to eliminate reflections from the back side of the piezoelectric element 1. If no backing plate 15 is provided, multireflection occurs and noise appears in received signals, which reduces sensitivity and resolution of the transducer head. Accordingly, if a printed wiring board is connected to the middle column or array, in parallel to the other printed boards 11, it must cross over the other arrays positioned on both sides of the middle column. This causes reflections. It is difficult to connect a printed wiring board vertically to the surface of the piezoelectric elements. The difficulty may be easily understood by considering the small size of the piezoelectric elements, 0.56 mm wide or less for example.

Therefore in a previously proposed transducer, as shown in Figs. 2(b) and 2(c), fine bonding wires 14 are bonded to each of the elements in the middle column. Then, backing plate 15 is formed by molding. After that, the free ends of the bonding wires 14 are bonded to respective terminals 17 formed on a terminal plate 16 which is attached on one side of the backing plate 15. In such a structure, however, the chance of short circuits between the bonding wires increases when the pitch of the array is decreased, and short circuits are apt to occur especially during the molding process of the backing plate 15. The difficulty of bonding wires to back electrodes 2A rapidly increases as the size and pitch of the unit piezoelectric elements is reduced. Further, it is difficult to keep the bonding wires 14 in the backing plate 15 straight and vertical to the plane of the matrix without suffering disconnections. If a bonding wire is bent in the backing plate 15, it causes reflection.

For the reasons described above, it has been difficult to decrease the pitch of the elements and increase the number of the columns in the matrix of the piezoelectric elements.

An embodiment of the present invention can provide a method of connecting a printed wiring board directly to each column of a matrix of piezoelectric elements in an ultrasonic transducer head.

An embodiment of the present invention can provide for a decrease in the pitch of the piezoelectric elements arranged in a matrix in an ultrasonic transducer, thereby allowing an increase in the resolution of a detector using the ultrasonic transducer.

An embodiment of the present invention can provide for an increase in the number of columns in a matrix formed by piezoelectric elements in an ultrasonic transducer head, and enable control of an acoustic beam to be effected not only in azimuthal directions but also in directions of elevation.

An embodiment of the present invention can provide for facilitation of the provision of wiring to each piezoelectric element in an ultrasonic transducer, and for increased production yield and transducer reliability.

An embodiment of the present invention can provide an ultrasonic transducer head of high resolution and having the ability to allow control of the ultrasonic beam radiated from it, not only in the azimuthal direction but also in the elevation direction.

In an embodiment of the present invention, a flexible printed wiring board is directly bonded to back electrodes of piezoelectric elements. Contact areas formed on the printed wiring board are arranged to meet respective back electrodes of piezoelectric elements arranged in a matrix. This particularly facilitates bonding to an inner column of elements of the matrix and to fine pitched piezoelectric elements. Then the printed wiring board is cut in an azimuthal direction, along a line corresponding to edges of the piezoelectric elements, and bent vertically to the surface of the matrix.

A backing plate is formed by molding. The back electrodes and a bonded end of a printed wiring board are buried into the backing plate. However, the other end of the wiring board protrudes from the molded surface of the backing

plate. In some cases extension boards may be used, so that the extension boards protrude from the backing plate.

Terminal pads of a printed wiring board are bonded to one edge portion of respective back electrodes. This reduces the acoustic reflection at the bonding point to a minimum.

In and for embodiments of the present invention methods of cutting to form a matrix of piezoelectric elements from a large piezoelectric element are provided.

One method of cutting is to cut a large piezoelectric element, which is stuck to a front matching layer, before a printed wiring board is bonded to its back electrodes. The cutting is effected from the back side of the large element, to form the matrix. Then a printed wiring board is aligned on the matrix, bonded, cut and bent vertically. After that the backing plate is molded.

Another method of cutting to form a matrix of piezoelectric elements is to cut a large piezoelectric element after the backing element is molded. Namely, a wiring board is bonded on to the back electrode of a large piezoelectric element. Bonding areas on the wiring board are arranged at positions corresponding to the matrix. So, bonding points are aligned on the large piezoelectric element in a matrix form. After bonding, the wiring board is cut in an azimuthal direction, bent vertically, and the backing plate is molded. Then the large piezoelectric element is cut to form the matrix of piezoelectric elements from its front side.

With this method of cutting, difficulties of bonding to a fine pitched matrix of piezoelectric elements are avoided.

Reference is made, by way of example, to the accompanying drawings, in which:-

Fig. 1 illustrates the appearance of an exemplary ultrasonic transducer head,

Figs. 2 illustrate schematically the structure of, and a bonding method employed for, a previously proposed ultrasonic transducer, wherein:-

Fig. 2(a) schematically illustrates the structure of a piezoelectric element;

Fig. 2(b) schematically illustrates how each of a matrix of piezoelectric elements is wired; and

Fig. 2(c) is a schematic partial perspective view of a transducer as shown in Fig. 2(b), after a backing plate has been molded thereon;

Figs. 3 illustrate schematically bonding of a printed wiring board to a matrix of piezoelectric elements, as provided in an embodiment of the present invention, wherein:-

Fig. 3(a) shows a matrix of piezoelectric elements cut out from a large-size element;

Fig. 3(b) shows a state in which a printed wiring board is bonded to the piezoelectric elements;

Fig. 3(c) is a side view corresponding to Fig. 3(b);

Fig. 3(d) illustrates a state in which the printed wiring board is cut and bent vertically to the surface of the matrix; and

Fig. 3(e) is a partial perspective view of the transducer structure with a backing plate molded in place, and an ultrasonic lens fixed;

Figs. 4 illustrate wiring pattern and construction of a wiring board used in Fig. 3, wherein:-

Fig. 4(a) is a plan view of the wiring pattern formed on the flexible printed circuit board; and

Fig. 4(b) is a schematic cross-section of the wiring board illustrating its structure;

Figs. 5 illustrate a form of bonding modified from that illustrated in Fig. 3, applicable when the matrix of piezoelectric elements has relatively few columns, in an embodiment of the present invention;

Fig. 5(a) shows a state in which a printed circuit board having a rectangular opening is aligned and bonded to a matrix of piezoelectric elements;

Fig. 5(b) is a side view corresponding to Fig. 5(a);

Fig. 5(c) is a side view of a state in which the printed circuit board is cut and bent vertically to the matrix surface; and

Fig. 5(d) is a partial perspective view of a state in which the backing plate is molded in place;

Fig. 6 illustrates a wiring pattern for the printed wiring board used for bonding as illustrates in Figs. 5;

Figs. 7 illustrate schematically an alternative method for cutting a large-size piezoelectric element into a matrix of elements, in accordance with an embodiment of the present invention, wherein:-

Fig. 7(a) shows a state when the printed wiring board is bonded to the large-size piezoelectric element;

Fig. 7(b) shows a state when the printed wiring board is cut and bent vertically to the piezoelectric element;

Fig. 7(c) shows a state when a backing plate is molded in place;

Fig. 7(d) is a partial perspective view, showing the reverse side of the structure, illustrating a state when the large size piezoelectric element is cut in an azimuthal direction;

Fig. 7(e) is an enlarged partially cutaway view corresponding to Fig. 7(d) illustrating the relation between the cutting slits and the printed wiring board; and

Fig. 7(f) illustrates a state when the front matching layer is attached to the piezoelectric elements.

Throughout the drawings, same or like reference numerals designate the same or similar parts.

The manner of providing wiring to each piezoelectric element of an ultrasonic transducer head, as provided by or in embodiments of the present invention, is explained below by reference to exemplary embodiments. Here, reference is made to a transducer head for ultrasonic tomography, by way of example only. The disclosed sizes, dimensions, numbers of columns, materials, and so on are all merely exemplary.

Figs. 3 illustrate the main steps relevant to the fabrication of an ultrasonic transducer, in accordance with an embodiment of the present invention, having 128 x 3 piezoelectric elements operated in a range of 3.5 MHz ultrasonic wave.

In Fig. 3(a), a large-size piezoelectric element 1′ is made of lead zirconate titanate for example, which is called PZT in the art. The size of the PZT element is about 100 mm long, 20 mm wide and 0.4 mm thick. The front and back sides of the PZT are metallized with silver to form front and back electrodes 2B and 2A respectively. A front matching layer 10, 0.2 mm thick, is formed by molding at the front electrode 2B. The front matching layer 10 is made from a conductive paste known by the trade name C-840, manufactured by Amicon, for example. The processes used are all conventional, so further details are omitted for the sake of simplicity.

Then the PZT is sliced from its back side by a slicer to cut out a matrix, leaving the front matching layer 10 as shown in Fig. 3(a). In this embodiment of the present invention, the large-size PZT element 1′ is divided into three parts by first cutting slits 12 which are parallel to the long edge of the PZT element 1′. This direction becomes an azimuthal direction. The element is further divided into 128 sections by second cutting slits 13 which are orthogonal to the first slits 12. The depth of these slits is adjusted to be deep enough to divide the piezoelectric elements 1 from each other, but not so deep as to cut apart the front matching layer 10, except at peripheral slits that cut the matrix off from the remainder of the large-size PZT element 1′. The width of these slits is 0.05 mm, and the pitches of the first and second slits are respectively 5 mm and 0.6 mm. As a result, a matrix of 128 x 3 piezoelectric elements is cut out from the large-size PZT element 1′. Each of the matrix elements is provided by a piezoelectric element 1 which is 4.5 mm long, 0.55 mm wide and 0.4 mm thick. So, the total size of the piezoelectric matrix is approximately 76.8 mm long and 15 mm wide.

Since the material forming the front matching layer 10 is conductive, the front electrodes 2B of all the piezoelectric elements 1 are electrically connected to each other. If the conductivity of the front matching layer 10 is insufficient, a thin foil of metal, such as silver, may be attached between the piezoelectric elements 1 and the front matching layer 10.

In the embodiment of the present invention a wiring board is bonded directly to each back electrode 2A of the piezoelectric elements. The wiring board is flexible, made of polimido (polyimide) sheet for example. A wiring pattern and structure of a wiring board are shown in Fig. 4, wherein Fig. 4-(a) is a plan view of the wiring pattern, and Fig. 4-(b) illustrates schematically a cross-section of the wiring board at a portion including a bonding area. Over a base film 30 made of polyimido (polyimide) sheet 25 µm thick, a metal foil (copper foil for example) 32, 35 µm thick, is glued by a binder 31, and the metal foil 32 is patterned as shown in Fig. 4(a) by photolithography. The entire surface of the wiring board 6 is covered with a cover coat film 36 to protect the surface of the board and to provide insulation of the wiring pattern. At portions corresponding to bonding areas 34 and the terminal pads 35 there are provided windows 37, to expose copper wiring lines 33 of the wiring pattern. The exposed portions of the copper wiring pattern are plated with solder 38.

The wiring lines 33 are spaced with a pitch equal to that of the piezoelectric elements 1 in the azimuthal direction. This pitch will be called the azimuthal pitch hereinafter. In this example, therefore, 128 parallel bonding lines 0.3 mm wide are aligned with a pitch of 0.6 mm. In practice, the width of the wiring lines 33 may exceed the width of the back electrodes 2A when the azimuthal pitch becomes very small, as long as insulation between lines is maintained.

At each portion of a wiring line 33 to be bonded to a back electrode 2A there is formed a bonding area 34. At predetermined portions on each of the wiring lines 33 terminal pads 35 are formed. The pitch p of the bonding areas 34 on each bonding line 33 is equal to the pitch of the matrix of piezoelectric elements (abbreviated to piezoelectric matrix hereinafter) in an elevation direction. This pitch is called the elevation pitch hereinafter. As can be seen in Fig. 4(a), on each wiring line 33, aligned pairs of bonding areas 34 and contact pads 35 are connected to each other by the wiring lines 33. The number of such pairs on each wiring line is equal to the number of columns in the piezoelectric matrix. Each of the pairs is aligned in series on the wiring line 33 in such a manner that the bonding area 34 of one pair is positioned as close as possible to the contact pad 35 of a neighbouring pair. The meaning and merit of this relationship between the positions of

the bonding areas 34 and the terminal pads 35 will become clear from the description regarding the next fabrication step.

The printed wiring board 6 described above is aligned on the piezoelectric matrix as shown in Figs. 3(b) and 3(c). Fig. 3(b) is a partial perspective view and Fig. 3(c) is a side view of this step. The wiring pattern shown in Fig. 4(a) is schematically indicated by broken lines. As can be seen in these Figures, each of the bonding areas 34 is aligned to one edge portion of a respective back electrode 2A. It will be understood that if one column of bonding areas 34 is aligned to edge portions of (one column of) back electrodes 2A of the matrix, all remaining bonding areas are also aligned to edge portions of corresponding back electrodes, since the azimuthal pitch and the elevation pitch of the bonding areas 34 are respectively equal to those of the piezoelectric matrix. So, the bonding areas 34 are soldered to respective bonding points 5 which are each positioned at an edge portion of a back electrode 2A, as can be seen in Figs. 3(b) and 3(c). This is a notable feature. Bonding is effected by means of a seam welder for example. Using such equipment, bonding to a plurality of bonding points can be accomplished in one shot.

Then, the printed wiring board 6 is cut along the lines CC′ which are parallel to the first slits 12, and positioned between the bonding areas 34 and the nearest terminal pads 35 as shown in Fig. 3(c) and Fig. 4(a). The cut printed wiring board 6 is then bent along the broken lines DD′ (Fig. 3(b) and Fig. 4(a)) vertically to the surface of the piezoelectric elements as shown in Fig. 3(d). The lines DD′ are almost aligned at the edge of the first slits 12. It will be apparent from Fig. 3(d), that each separated printed wiring board 6′ is L-shaped, soldered at one edge portion of piezoelectric elements 1 aligned in the azimuthal direction, and extends vertically from the surfaces of the piezoelectric elements. These features serve to reduce sound reflection at bonding points. Amplitude of oscillation of a piezoelectric element is smaller (at an edge) than at a centre part of a back electrode. Since the printed wiring board pieces extend vertically from the surface of the piezoelectric elements, reflection from the wiring board pieces is avoided or mitigated, because ultrasonic waves radiated backwards from the piezoelectric elements travel parallel to the printed wiring board pieces 6′, and are absorbed by a backing plate 15. This is another notable feature.

Next, backing plate 15 is formed on the back of the piezoelectric elements by molding. A mixture of epoxy resin and metal powder, tungsten for example, is used for the backing plate 15. The mixing rate may be varied depending on the wavelength of the ultrasonic waves and the required dumping factor. The other ends of the separated wiring boards 6′ protrude from the molded surface of the backing plate 15 as shown in Fig. 3(e). In the Figure, the printed wiring board 6 is bent vertically along a side of the backing plate 15. Finally, an acoustic lens 7 is attached to the front matching layer 10. The acoustic lens is made of silicon rubber for example. Terminal pads 35 are connected to a multicored cable (not shown) and connected to a controller.

If the thickness of the backing plate 15 exceeds the height of an L-shaped wiring board 6′, the length of the wiring board may be elongated by bonding a supplementary board to the terminal pads 35. For example in this embodiment, epoxy resin and tungsten powder having a diameter of 3-50 μm have been used with a mixing ratio of 300 to 600 % in weight. On the other hand, the height of the L-shaped printed wiring boards was approximately 4 mm. So, the separated printed wiring boards 6′ are elongated by bonding additional wiring boards 6″ (having almost the same pattern as shown in Fig. 4(a)). The bonding of these additional wiring boards is easily effected using the terminal pads 35. .

It will be understood from the above description that the bonding of printed wiring board(s) to all of the piezoelectric elements is very much facilitated, so that the bonding can be applied to piezoelectric matrixes having finer pitches. Further, although in the example given only three columns are provided in the matrix of piezoelectric, it will be understood that more columns can be provided in the matrix.

With reference to Figs. 5 a modification or alternative, in accordance with an embodiment of the present invention, will be described. This embodiment is especially convenient when the number of columns in the matrix is small. In Fig. 5 piezoelectric elements are shown arranged in a matrix having three columns. The formation of the matrix is accomplished in the manner described with reference to Figs. 3. The wiring pattern of printed wiring board 3 is shown in Fig. 6. In the Figure, the wiring pattern is shown without a cover coat 36 covering the surface of the wiring board. The structure of the printed wiring board is, however, essentially similar to that of Fig. 4(b).

The printed wiring board 3 is provided with a rectangular opening 4. The length of the opening 4 is equal to the length of the piezoelectric matrix, and the width of the opening is less than two elevation pitches by twice the length of the bonding area. On each of the long sides of the rectangular opening 4 a wiring pattern is provided which is similar to that of Fig. 4(a). The wiring lines 33, 33′ of respective wiring patterns are all terminated at the rectangular opening 4. The wiring lines 33 and

33′ are all similar to those of Fig. 4, except that on the wiring lines 33 two bonding area/terminal pad pairs (bonding area 34 and terminal pad 35) are aligned, while on the wiring lines 33′ only one such pair is aligned. the relative positions of these bonding areas are all similar to those of Fig. 4(a), except that bonding areas 34′ are positioned along the rectangular opening 4.

Fig. 5(a) is a partial perspective view, and Fig. 5(b) is a side view illustrating a state when the printed wiring board 3 is aligned to the piezoelectric element matrix. The pattern and the rectangular opening 4 of the printed circuit board 3 is designed so that the major parts of a first column 1a and a second column 1b of the matrix are exposed through the rectangular opening 4, but a third column 1c of the matrix is covered entirely by the printed wiring board 3. Bonding areas 34 and 34′ are aligned respectively to side portions of corresponding back electrodes 2A of the first column 1a and the second column 1b. As will be apparent from Fig. 5(b), bonding areas 34′ are positioned on the opposite side of back electrodes 2A in column 1a, corresponding to that of the bonding pads 34 aligned to the second column 1b. By doing this, both ends of the printed wiring board 3 are extended outward from the piezoelectric matrix. This minimizes backward reflection. The aligning of the printed wiring board is easier compared to that of the structure of Figs. 3. The bonding areas are bonded to respective bonding points 5.

After cutting the printed wiring board at a line EE′, the printed wiring board is bent along broken line DD′ vertically to the matrix as shown in Fig. 5-(c). The line EE′ is parallel to first slits 12, and positioned between the bonding areas 34 and the nearest terminal pads 35 as shown in Fig. 5(a) and Fig. 6. The broken line DD′ is aligned to the first slits 12. Then, backing plate 15 is molded over the matrix surface as shown in Fig. 5(d). The cut edge of each separated piece 3′ of the printed wiring board protrudes from the surface of the molded backing plate 15. It will be apparent that the form of Fig. 5(d) is equivalent to that of Fig. 3(e). The succeeding processes are similar to those described with reference to Figs. 3.

The provisions of a further structure, in accordance with embodiments of the present invention, will be described with respect to Figs. 7. In this structure, large-size piezoelectric element 1′ is cut from its front side after printed wiring board 6 has been bonded and backing plate 15 molded. Figs. 7 illustrate main fabrication steps.

First, as shown in Fig. 7(a), a printed wiring board 6 is placed on the back of a large-size piezoelectric element 1′. The printed wiring board 6 is similar to that shown in Figs. 4. Though not shown in Figs. 7, for the sake of simplicity, both sides of the large-size piezoelectric element 1′ are metallized to form front and back electrodes. Bonding areas (not shown) are bonded to the back electrode, the printed wiring board 6 is cut in an azimuthal direction, and bent vertically to the surface of the piezoelectric element in a manner as described with reference to Figs. 3. The appearance of the structure at this stage is then as shown in Fig. 7(b). Backing plate 15 is then molded as shown in Fig. 7(c), in a manner as described with reference to Figs. 3.

When the device is turned over, the front side of the piezoelectric element 1′ appears on the top of the structure as shown in Fig. 7(d). The large-size piezoelectric element 1′ has been cut from its front side using a slicer, for example. Fig. 7(d) shows a state in which element 1′ has been cut in the azimuthal direction to form two first slits 12. The positions of the first slits 12 are aligned to be just outside of L-bend corners 8 of the separated print wiring boards 6′, as shown in Fig. 7(d). Therefore, the first slits 12 do not harm the printed wiring boards 6 or 6′ buried in the back plate 15. The large-size piezoelectric element 1′ is then cut along second slits 13 which are perpendicular to the slits 12, and which are separated with a pitch equal to the azimuthal pitch of the piezoelectric matrix.

Fig. 7(e) is an enlarged partially cut-out view illustrating the relationship between the cutting slits and the printed wiring board. The large-size piezoelectric element 1′ is cut along the second slits 13 which are orthogonal to the first slits 12. The depth of these slits 12 and 13 is greater than the thickness of the piezoelectric element 1. So, as can be seen in the Figure, both of the slits are cut into the backing plate 15. By doing so, the printed wiring board 6 is partially cut by the second slits 13. The second slits 13 are aligned between the wiring lines 33, in parallel to them. Accordingly, the slits do not damage the wiring pattern. If the azimuthal pitch becomes very small, the second slits 13 may cut the sides of wiring lines 33. Even in such case, however, the function of the wiring lines 33 is not lost, and insulation between the lines is also maintained. Further, it is found that such over-cutting of the slits into the backing plate 15 is preferable to reduce the interaction between the adjacent piezoelectric elements.

Then, the front matching layer 10 is attached as shown in Fig. 7(f). The state of Fig. 7(f) is equivalent to that of Fig. 3(e), when the acoustic lens 7 is attached to it.

Comparing the structure of Figs. 7 with that of Figs. 3, etc., it will be understood that the handling of the elements is facilitated in Figs. 7. The method of cutting the large-size piezoelectric element in Figs. 7 has been described with regard to a device generally similar to that of Figs. 3. However, it will

be apparent that the cutting method described in Figs. 7 may be applied also to the structure of Figs. 5.

Embodiments of the present invention provide ultrasonic transducers having a plurality of piezoelectric elements arranged in a matrix, and method for fabricating such transducers.

L-shaped printed wiring boards are respectively bonded to arrays of piezoelectric elements arranged in azimuthal directions. The bonding points of an L-shaped printed wiring board to respective piezoelectric elements are located at edge portions of respective back electrodes. The other branch of the L-shaped printed wiring board is extended vertically to the surface of the piezoelectric elements matrix. A backing plate is formed by molding on the back side of the piezoelectric elements matrix leaving the top of the L-shaped printed wiring board protruding from the molded surface of the molded backing plate. Such configuration prevents reflection from the wiring plate of the piezoelectric element

A flexible printed wiring board is provided with a wiring pattern having bonding areas positioned corresponding to a matrix of piezoelectric elements. So, the bonding of the printed wiring board to each of the piezoelectric elements is easy. After the bonding, the printed wiring board is cut and bent vertically to the matrix surface to form the L-shape. The matrix of piezoelectric elements may be cut out from a large-size piezoelectric element before the molding of the backing plate or after its molding.

Claims

1. An ultrasonic transducer having a plurality of piezoelectric elements arranged in a piezoelectric matrix comprising a plurality of piezoelectric arrays aligned in parallel one to another, each of said piezoelectric arrays comprising a plurality of said piezoelectric elements aligned in an azimuthal direction, and each of said piezoelectric elements having a front electrode and a back electrode between which electrical potential can be applied to energize the piezoelectric element and radiate an ultrasonic wave or between which electrical potential can be generated in response to reception of an ultrasonic wave, said ultrasonic transducer comprising:-

a front matching layer attached to each of said front electrodes of said piezoelectric elements, for matching acoustic impedance between said piezoelectric elements and a medium into which an ultrasonic wave is to be transmitted or from which an ultrasonic wave is to be received;

a backing plate provided on the back side of said piezoelectric elements for absorbing ultrasonic waves travelling backward from said piezoelectric elements, to prevent reflection from the backward portion of said piezoelectric elements; and

at least one L-shaped printed wiring board, the or each such board being aligned to a respective piezoelectric array, the or each such board having:-

a plurality of bonding areas positioned on one arm of the L-shaped printed wiring board, each of said bonding areas being bonded to the back electrode of a respective piezoelectric element in the piezoelectric array with which the board is aligned;

a plurality of terminal pads provided on the other arm of the L-shaped printed wiring board; and

a plurality of wiring lines for electrically connecting said bonding areas to respective terminal pads,

said other arm of the L-shaped printed wiring board extending vertically away from the back electrodes of the relevant piezoelectric array, through the backing plate.

2. A transducer as claimed in claim 1, wherein each of said bonding areas on the or each L-shaped printed wiring board is bonded to an edge portion of the back electrode of a respective piezoelectric element arranged in the array with which the board is aligned.

3. A transducer as claimed in claim 1 or 2, wherein the or each L-shaped printed wiring board is composed of a flexible printed wiring board, one end of which is provided with said bonding areas and provides one arm of the L-shaped printed wiring board, while another end of the printed wiring board is provided with said terminal pads and is bent vertically with respect to the back electrodes of the piezoelectric elements of the relevant piezoelectric array, to form the other arm of the L-shaped printed wiring board.

4. A transducer as claimed in claim 1, 2 or 3, wherein the other arm of the or of at least one L-shaped printed wiring board is extended in length by bonding an additional printed wiring board thereto, so that one end of said additional printed wiring board protrudes from the back surface of the backing plate.

5. A method for fabricating an ultrasonic transducer having a plurality of piezoelectric elements aligned in a piezoelectric matrix, said piezoelectric elements being separated from each other by first slits aligned in parallel to an azimuthal direction and separated from each other with an elevation pitch, and second slits aligned orthogonally to said first slits and separated from each other with an azimuthal pitch, and each of said piezoelectric elements having a front electrode and a back electrode, said method comprising the steps of:-

(a) preparing a flexible printed wiring board having a wiring pattern comprising:-

a plurality of bonding areas arranged in a matrix having an azimuthal pitch and an elevation pitch respectively equal to those of the piezoelectric matrix;

a plurality of contact pads each of which corresponds to a respective bonding area; and

a plurality of wiring lines for connecting each bonding area to a corresponding contact pad;

(b) aligning said flexible printed wiring board on back electrodes of said piezoelectric elements, so that each bonding area is aligned with one edge portion of the back electrode of a corresponding piezoelectric element, and bonding each of said bonding areas to the corresponding back electrode edge portion;

(c) cutting said printed wiring board along lines which are parallel to said first slits and positioned between bonding areas and their nearest neighbour contact pads;

(d) bending the free end of at least one separated piece of said flexible printed wiring board, separated by cutting in process (c), vertically with respect to the surfaces of the back electrodes; and

(e) forming a backing plate by molding, on the back side of said piezoelectric elements.

6. A method as claimed in claim 5, wherein said flexible printed wiring board includes a rectangular opening, the length of which is equal to the length of said matrix of piezoelectric elements, and the width of which is less than two elevation pitches by twice the length of a bonding area, and on each longer side of said rectangular opening there being provided a wiring pattern similar to that of claim 5.

7. A method of fabricating an ultrasonic transducer having a piezoelectric matrix which is composed of a plurality of piezoelectric elements arranged in azimuthal and elevation directions respectively with azimuthal and elevation pitch, the method comprising the steps of:-

(A) preparing a large-size piezoelectric element of an area sufficient to cover the piezoelectric matrix, the thickness of the large-size element being equal to that of the piezoelectric matrix, front and back sides of the large-size piezoelectric element being respectively provided with front and back electrodes;

(B) aligning a flexible printed wiring board on the back electrode of the large size piezoelectric element, said flexible printed wiring board having a wiring pattern comprising:-

a plurality of bonding areas arranged in a matrix having azimuthal pitch and elevation pitch respectively equal to those of the piezoelectric matrix

a plurality of contact pads, each corresponding to a respective bonding area; and

a plurality of wiring lines for connecting each bonding area to a corresponding contact pad;

(C) cutting said printed wiring board in the azimuthal direction along the lines which are positioned between the bonding areas and their nearest neighbour contact pads;

(D) bending the free end of at least one separated piece of said flexible printed wiring board, separated by cutting in process (C), vertically with respect to the surface of the back electrode; and

(E) forming a backing plate by molding on the back side of the large-size piezoelectric element;

(F) cutting said large-size piezoelectric element from its front electrode side in both azimuthal and elevation directions respectively with the azimuthal pitch and elevation pitch appropriate to form the matrix of piezoelectric elements; and

(G) forming a front matching layer attached to each of the front electrodes of piezoelectric elements for matching acoustic impedance between the piezoelectric elements and a medium into which an ultrasonic wave is to be transmitted or from which an ultrasonic wave is to be received.

8. A method as claimed in claim 7,wherein the flexible printed wiring board further comprises a rectangular opening, the length of which is equal to the length of said piezoelectric matrix in an azimuthal direction, and the width of which is less than two elevation pitches by twice the length of a bonding area, and on each longer side of said rectangular opening there being provided a wiring pattern similar to that of claim 7.

9. A method as claimed in claim 5, 6, 7 or 8, further comprising a step for bonding an additional wiring board to the or each bent piece of printed wiring board to extend the length thereof so that an end of the or each additional board protrudes from a back surface of the backing plate.

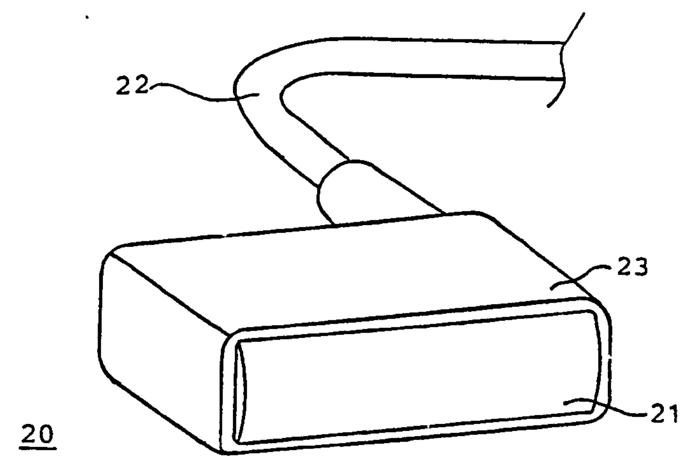


FIG. 1

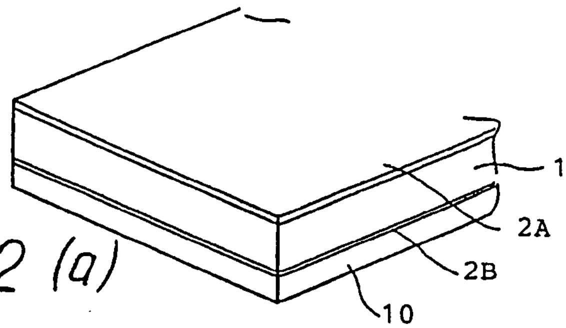


FIG. 2 (a)

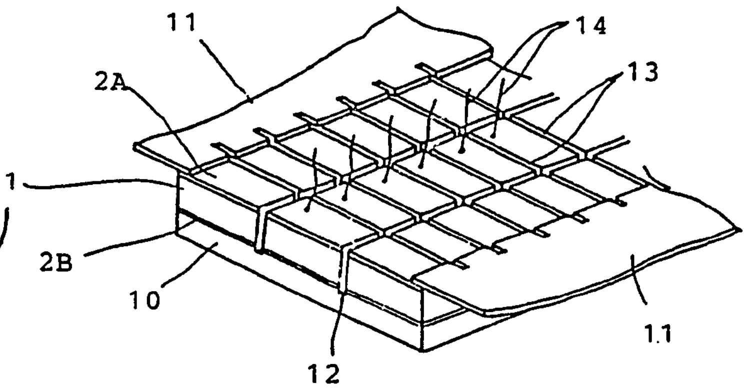


FIG. 2 (b)

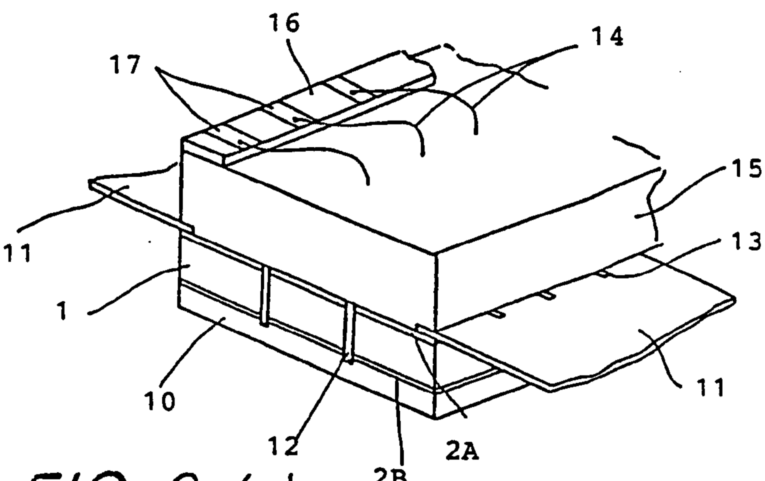


FIG. 2 (c)

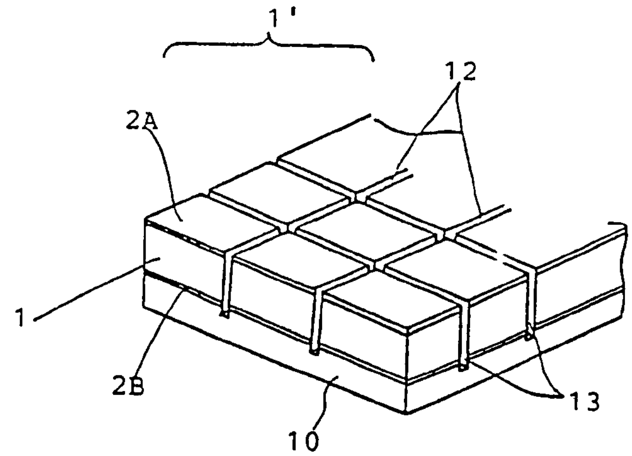


FIG. 3 (a)

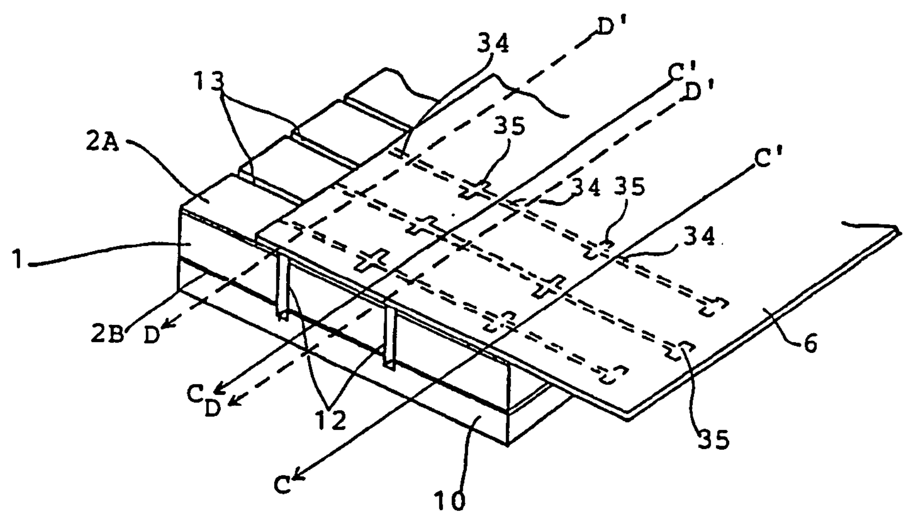


FIG. 3 (b)

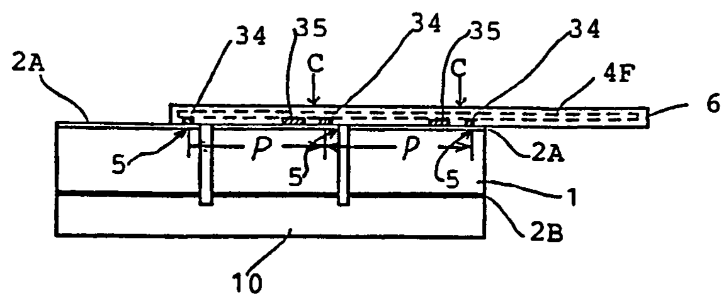


FIG. 3 (c)

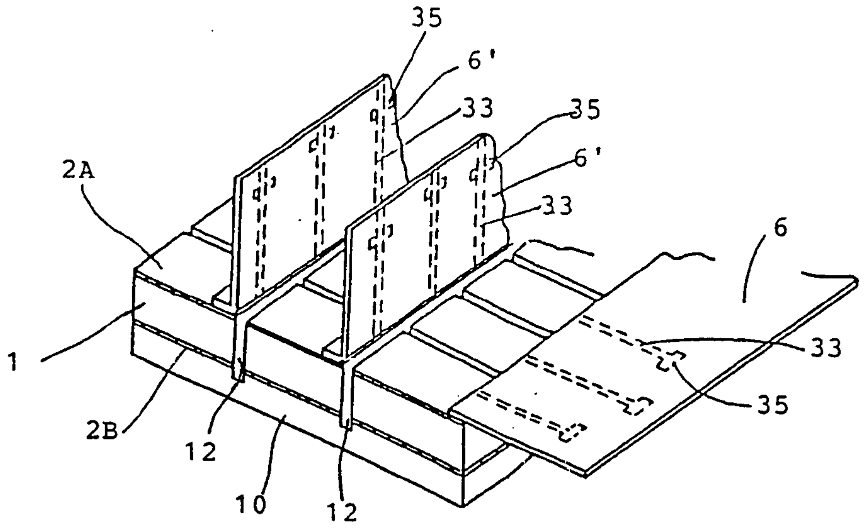


FIG. 3 (d)

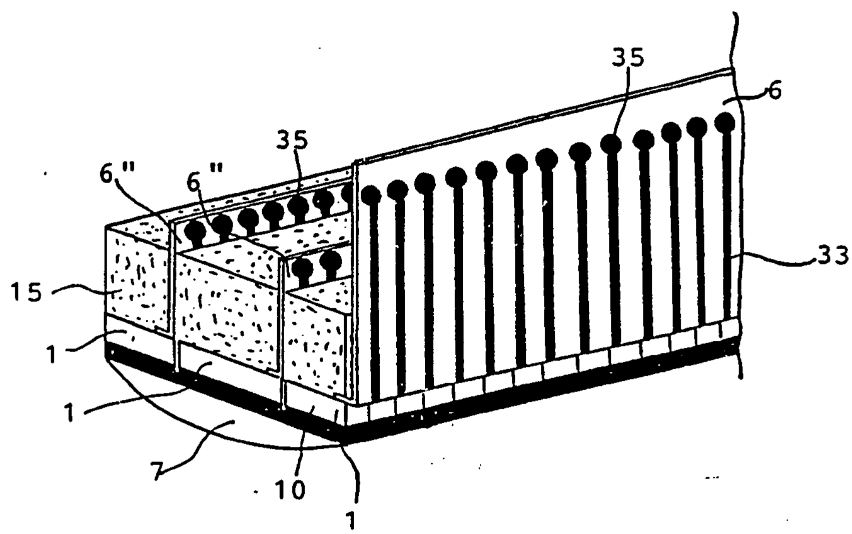


FIG. 3 (e)

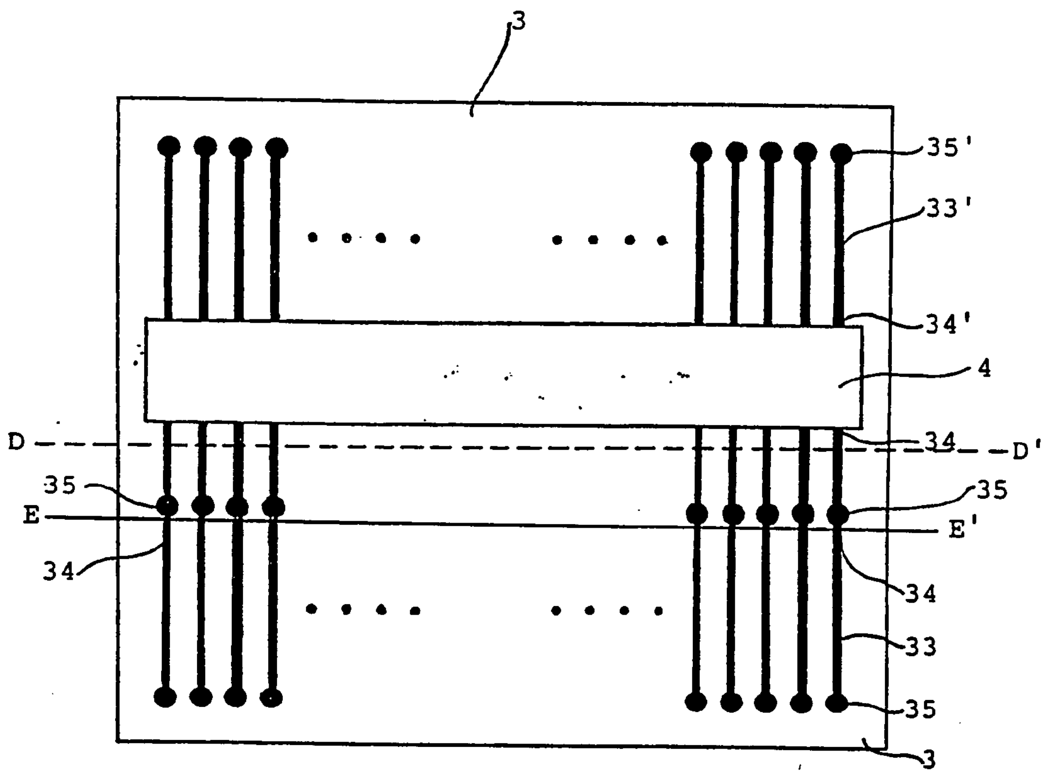


FIG. 6

FIG. 7 (a)

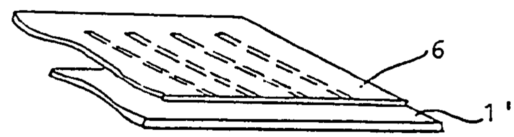


FIG. 7 (b)

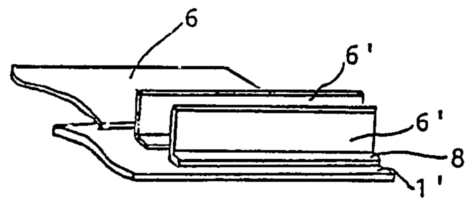


FIG. 7 (c)

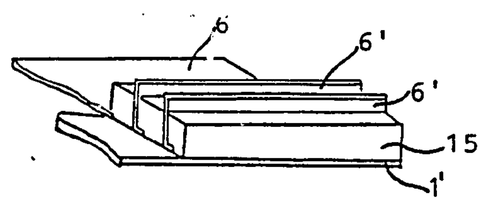
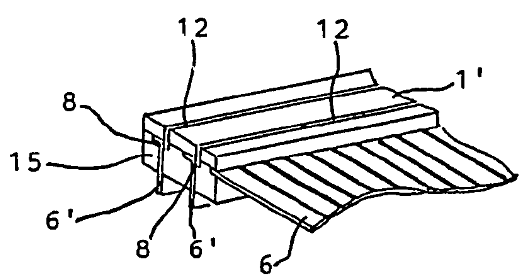


FIG. 7 (d)



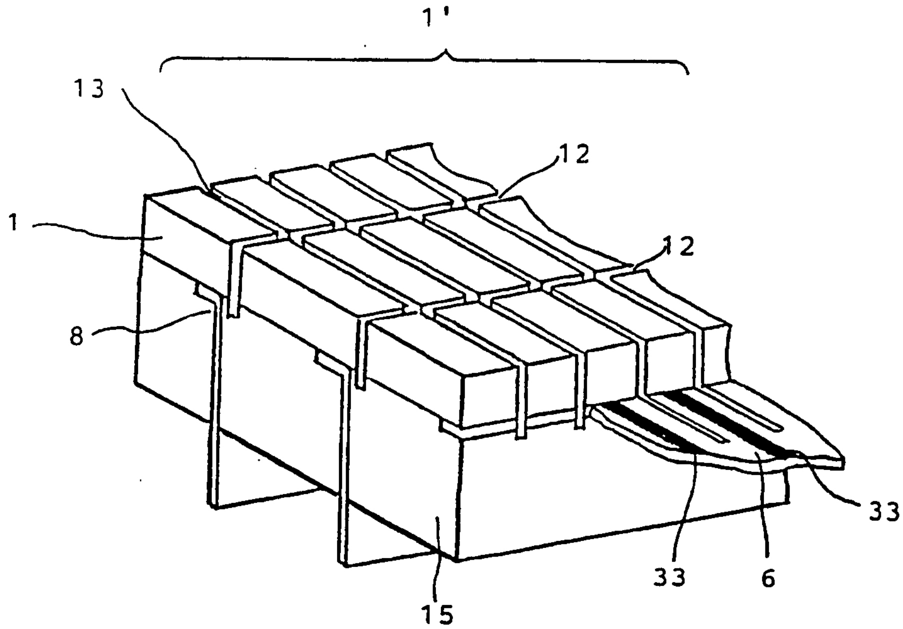


FIG. 7 (e)

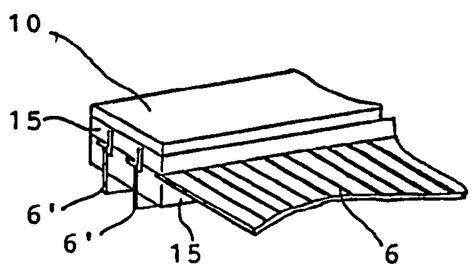


FIG. 7 (f)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 88 10 9267

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	PATENT ABSTRACTS OF JAPAN, vol. 9, no. 4 (E-288)[1727], 10th January 1985; & JP-A-59 152 800 (YOKOKAWA MEDICAL SYSTEM K.K.) 31-08-1984 * Abstract; figures * ---	1-5,7	G 10 K 11/34
A	GB-A-2 086 269 (HEWLETT-PACKARD CO.) * Abstract; page 1, lines 31-69; page 1, line 107 - page 2, line 28 * ---	1-3,5,7	
A	US-A-4 479 069 (MILLER) * Abstract; column 1, lines 35-64; column 3, lines 8-68 * ---	1-3,5,7	
A	DE-A-3 623 520 (ADVANCED TECHNOLOGY LABORATORIES INC,) * Abstract; column 3, line 7 - column 4, line 35 * ---	1-3,5,7	
A	US-A-4 638 468 (FRANCIS) ---		TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	EP-A-0 025 092 (SIEMENS AG) -----		G 10 K G 01 S H 05 K H 01 L B 06 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22-09-1988	OLDROYD D.L.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)